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Biological Treatment for Slaughterhouse Wastewater Via Horizontal Flow Biofilm Reactor

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Abstract

Slaughterhouse wastewater (SWW) is a typical source of pollution and creates serious environmental concerns. Therefore, SWW needs a cost effective and efficient treatment technology for safe discharge and consequently for public health protection. The aim of the study was to evaluate the treatment of SWW by two steps, first one was primary treatment by screening and settling followed by biological treatment using of Horizontal Flow Biofilm Reactor (HFBR) as a second step. A significant review of raw SWW characteristics was presented, COD, BOD and TSS concentrations values were very high its maximum values reached 9855, 5037 and 3440 mg/l, respectively. The primary treatment removed 34% COD and 75% TSS. The performance of HFBR system has been investigated in continuous mode. The system was operated at two different organic loading rates to find out the optimum operating conditions, which produce treated effluent characterization compatible with the Egyptian legislation for discharge on sewerage network. The organic loads (OLR) applied to the HFBR system were 0.53 and 1.3 kg COD/m2/d. During the steady-state of optimum operating conditions, the system achieved significant carbon removal of 85% and 95% for COD and TSS respectively. Nitrogen removal percentage reached 50% ammonia-nitrogen and 56% for total nitrogen. From the results obtained HFBR could be considered as a reliable treatment technology for SWW.

Key words: Slaughterhouse, wastewater, biological treatment, HFBR, biodegradability

1. INTRODUCTION

Slaughterhouse wastewater has been classified as industrial wastewater in the category of agricultural and food industries [1]. SWW contains high concentration of organic matter which is partially soluble, leading to a highly polluting effect, deoxygenating of rivers and contamination of groundwater [2, 3]. The deterioration of surface water quality has become a thoughtful problem due to anthropogenic activities like agriculture activities [4, 5]. According to EPA and different European legislations SWW considered the most polluting and harmful to the environment [6, 7]. It contains high levels of organics such as BOD, COD, nitrogen and phosphorous due to the presence of blood. One of the major dissolved pollutants, fats, grease, proteins, suspended solids and may also some manure [8, 9]. Aniebo [10], stated that the effluent load of the blood from a single cow would be equivalent to the total sewage produced by 50 people on average day. Slaughterhouse wastewater contains high concentration of nitrogenous compounds when discharged to receiving water bodies’ leads to undesirable problems such as algal blooms and eutrophication in addition to deoxygenation of rivers [1, 11]. Discharging of untreated SWW contributes greatly to the contamination of groundwater [12] and pollution of irrigation water [13].

In Egypt, the slaughterhouses working under the supervision of Veterinary units in the “Ministry of Agriculture”. It mostly distributed all over the Nile banks in cities and villages, and discharge their wastewater into the nearby water drainage without any kind of treatment. Thus, it is necessary to apply an appropriate treatment technology to control the discharge of carbon and nitrogen concentrations loaded in this wastewater. Biological treatment by different types of technologies has been efficiently proved that it is the most appropriate way of slaughterhouse wastewater treatment [14, 15, 16]. Aerobic treatment processes are restricted because of their high energy consumption, high sludge production and it is sensitive to high organic loads [17, 18]. Also, the anaerobic treatment is effective and economical, but require long hydraulic retention time and large reactor volumes, due to the accumulation of suspended solids and floating fats in the reactor which lead to a reduction in the methanogenic activity and biomass wash-out [19]. Thus, there is an essential need of high biomass concentration and controlling of sludge loss, to avoid

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the wash-out of the sludge [20]. The biofilm wastewater treatment technology is now commonly used to treat high strength wastewaters because of the availability of high specific surface- area for the plastic media. It has many advantages such as reduced sludge production; high sludge age benefiting slow growing of bacteria, such as nitrifies and provide additional nutrient removal [21]. The horizontal flow biofilm reactor (HFBR) is a simple treatment technology with a flexible design which provides a new effective and inexpensive technology for carbon and nitrogen removal from wastewaters [22, 23, 24]. The HFBR technology has many advantages in contrast with other conventional biofilm reactors [25]. The system can easily be adapted to different organic loads by increasing or reducing the number of sheets or the plane surface area. It has high removal values of nitrogen and carbon concentrations as well as low running and maintenance costs.

2. MATERIALS & METHODS

2.1. Source of Slaughterhouse Wastewater

SWW used was collected from slaughterhouse in Giza Governorate, this firm doesn't apply any kind of treatment. It discharged all of it by the end of pipe in El-Mariotia Canal.

2.2. Physico-Chemical Characteristics

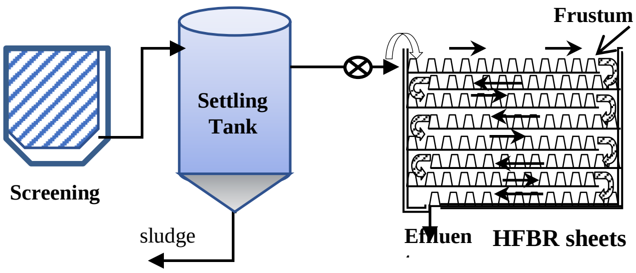
All physico-chemical analysis was carried out according to the American Public Health Association for Examination of Water and Wastewater [26]. Monitoring study of raw SWW characteristics was performed to make an evaluation of wastewater characterization.

2.3. Aerobic Biodegradability test for SWW

Prior starting the biodegradability test, the biomass was acclimatized and grown on SWW in aerated five liters plexiglass laboratory column. The food to microorganism (F/M) ratio was ranging between 0.4 to 0.6gCOD/gVSS. Biodegradability experiment was conducted on an experimental plexiglass laboratory column four liters volume, consists of a plexiglass basin containing air ducts at its bottom. The column was inoculated with acclimatized activated sludge (3-4g/l) and the settled SWW was added to the sludge. Dissolved oxygen concentration was adjusted to $2mgO_2/l$. Samples from the column inoculated with adapted biomass were collected at 0 to 72 hours of reaction time. Samples were settled for 60 minutes and the clear supernatants were subjected for BOD and COD analysis. The ratio of BOD elimination, corrected for the blank, to the initial BOD value is expressed as the percentage biodegradation.

2.4 Treatability study

The treatment process is summarized in, primary treatment consists of screening and settling for 24 hrs. followed by biological treatment using HFBR as a secondary treatment. Schematic diagram (1) cleared the treatment processes.



Schematic diagram (1) of the treatment

2.4.1. Primary Treatment

SWW primarily treated in the project site using screening followed by sedimentation. SWW passed through a fine screen installed to remove the dispersed particles larger than 1 mm and floating material from wastewater. Screened SWW settled in a round sedimentation tank for 24 hours. To determine the optimum settling time, a plain sedimentation experiment was performed in an Imhoff cone, the settled SWW was collected at different settling time intervals starting from 0.5hour till 24hrs, for COD and TSS analysis.

2.4.2. Secondary Biological Treatment using Horizontal Flow Biofilm Reactor

a) Design and Construction of HFBR system

HFBR consists of five units which contains 40 horizontal polyvinyl chloride sheets (PVC) positioned one above the other. Each sheet measured 380mm×280mm×5mm supported by a frame and it contains vertical frustums (Schematic Diagram 1). The frustums increased the available biofilm plan surface area and provided for solids accumulation. The total plane surface area (TSA) of the sheets was equal $4.3m^2$.

b) Startup and operation of the HFBR system

HFBR system was operated for 30 days before starting to operate the applied ORL in order to reach steady-state conditions. The primary treated SWW was pumped continuously onto the top of the reactor and flowed horizontally along each sheet and vertically from sheet to sheet down through the reactor. Steady state was defined by the constant effluent COD concentration value within, 5% variation for three consecutive measurements. After reaching the steady state condition; the system operated for one year; under two organic loading rates equal to 0.53 and 1.3kg COD/m^2/d.

c) Evaluation of the efficiency and performance of the HFBR system

Performance of the HFBR system was monitored by analyzing the influent and the final effluent from the reactors. The primary treated SWW was fed to the HFBR from the feed tank and the final treated effluent collected from the settling tank after the last sheet of the reactor. Samples also collected and analyzed from different units down through the reactor. The removal percentage(R%) was calculated according to the following equation

$$\%R = \left(\frac{Ci - Ce}{Ci}\right) \times 100$$

Ci = influent concentration mg/l
Ce = effluent concentration mg/l

3. RESULTS & DISCUSSION

3.1 Characterization of Raw SWW

Physico-chemical characteristics of raw SWW, are recorded as average values in Table (1). COD, TSS and oil & grease concentrations were very high with average values of 7065, 1610 and 337 mg/l respectively. The results indicated that slaughterhouse wastewater can be classified as strong strength and it is 1 to 10 times higher than strong domestic wastewater due to the presence of significant volume of blood reaching the end-off-pipe and also referred to the handling of the intestines and stomach contents [27; 28; 29].

Characterization of the primary treated SWW is recorded in Table 1. The data indicated that 12% of suspended solids were removed by screening and only 17% of total COD was removed. Plain settling experiment was conducted to determine the best settling time for screened SWW. The results showed that COD removal values increased by increasing settling time; 29% of COD removed after 0.5 hr. and 41% after 3hours. After twenty-four hours settling the COD and TSS removal values were 47% and 75% respectively. It can be concluded that the primary treatment of using screening followed by 24 hrs. settling of SWW must be implemented and it can't be excluded as it reduces the organic load and preventing any clogging in the secondary treatment system.

Primary treated SWW characterization showed high fluctuation of COD, BOD and TSS concentrations. COD concentration values ranged between 1560 to 10369 mg/l. Soluble COD fraction was an average of 53% of the total COD. BOD fluctuated between 533 to 5037 mg/l, and TSS ranged between 152 to 3440 mg/l. Primary treated SWW BOD_5/COD ratios recorded over the studying time ranging from 0.6 to 3.8 with an average of 2.3; these numbers are comparable to those presented by [30]. COD / TKN ratio was ranging between 2 to 33 with an average of 13.9 and the COD /organic nitrogen ratio was ranging between 15 to 92, this indicated that the organic matter mainly consisted of protein.

3.2 Biodegradability Test:

The biodegradation of SWW have been estimated under aerobic conditions. According to the results obtained, it was found that the BOD removal was 73% after the first hour and it increased to 82% and 95% after 6 hrs. and 24 hrs. respectively. Average percentage biodegradability ranged between 25% after 1hr, 18% after 5 hrs. Biodegradability percentage became constant by 4% after 24hrs. and 48 hrs. then decreased to 0% after 72 hrs. Thomas graphical method was applied to determine BOD rate constant (k) and ultimate BOD (Lo), the Thomas relationship is given by the following equation:

$$\left(\frac{t}{BODt}\right)^{\frac{1}{3}} = \frac{1}{(kLo)^{\frac{1}{3}}} + \frac{k^{\frac{2}{3}}}{6(Lo)^{\frac{1}{3}}} * t$$

The linear graph based on Thomas graphical method is shown in Figure (1). The value of BOD rate constant (k) and ultimate BOD (Lo) were 0.374/day and 534 mg/l, respectively.

3.3. Biological Treatment:

Determination of the HFBR optimum operating conditions

To evaluate the HFBR system performance, two different organic loading rates (OLR) were applied namely, 0.5 kg COD/m^2/day and 1.3 kg COD/m^2/day, with corresponding hydraulic loading rate (HLR) of 0.2 m^3/m^2/day and 0.3 m^3/m^2/day. There was considerable variation in the COD concentration values in raw SWW which affects the OLR applied to the system.

Table (1) Average* Characterization of Raw wastewater prior and after primary treatment

Parameters	Units	Non-screened SWW	Screened SWW	% Removal	Settled SWW (Primary treated)	% Removal
pH		7.7	7.5		7.5	
Chemical Oxygen Demand (COD)	mgO_2/l	7065±3721	5196±1563	17%	4651±1931	34%
Biological Oxygen Demand (BOD)	mgO_2/l	3636±1849	2777±668	20%	2028±1045	41%
Total Suspended Solids (TSS)	mg /l	1610±815	1208±409	12%	577.6±273	75%
Phosphorous	mg /l	18.4±22	13±6	24%	10.7±8.3	35%
Ammonia	mg /l	255±373	242±149	4%	233±176	10%
Organic Nitrogen	mg /l	163±38	149±93	7%	130±43	17%
Oil &Grease	mg /l	337±276	218±96	30%	150±135	52%

*Average of 40 samples

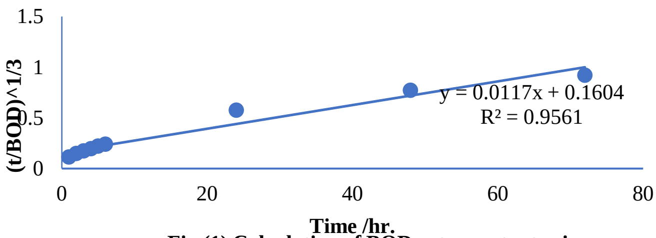


Fig.(1) Calculation of BOD rate constant using Thomas graphical method

3.3.1 First load

HFBR was operated at ORL namely 0.5 kg $COD/m^2/day$ for about six months. The results are presented in Table (2) and illustrated graphically in Figures (2-3). COD residual concentration values ranged between 127 to 680 mg/l with an average value of 346 mg O_2/l. Corresponding, BOD average concentration values ranged between 49 to 318 mg O_2/l in the final effluent. Also, average TSS concentration value reached 41.5 mg/l and it was ranged from 10 to 108mg/l. Oil & grease value dropped significantly to 18.6 mg/l in the final effluent. The system gives high removal efficiency in organic carbon and nitrogen removal in this load, the COD removal percentage ranged between 74 and 91% with an average 85%, and BOD ranged between 57% and 95% with an average of 86%. Average removal values of TSS and oil& grease reached 91% and 75% respectively. Total Kjeldahl Nitrogen removal was around 56% but its residual concentration still high in the effluent in the same time most of the organic nitrogen was converted to ammonium. The Ammonia concentration was 63% of the TKN concentration in the raw SWW this percentage increased to a range between 50% to 90% in the final effluent. These results detected also in using SBR system for treating SWW [31].

3.3.2 Second load

The system operated for six months under OLR equal 1.3 kg $COD/m^2/day$. The results obtained showed that residual concentration value of COD was ranging between 181 to 1771 mg/l (Table 2 &Figure 2) with an average value of 970 mg O_2/l. Corresponding, BOD average concentration value ranged between 391 and 883 mg O_2/l in the final effluent. Also, TSS average concentration was 45 and it was ranged from 28 to 100mg/l (Figure 3). Oil & grease concentrations in the final effluent ranged between 32 to 84 mg/l with an average of 33 mg/l. Removal efficiency, dropped in this load by about 10% for COD and BOD but for ammonia it dropped by about 20% (Table 2). COD removal percentage ranged between 57 and 93% with an average 76%. Also, BOD removal percentage ranged between 49% and 93% with an average of 71%. The system achieved high removal values of TSS reached 98%.

3.3.3 Performance evaluation of HFBR through regular monitoring of the treated effluent from Selected sheets

In the HFBR, dissolve oxygen penetrated into the biofilm by air diffusion. DO concentration of 4-5 mg/l

Table (2) Average* Characterization of influent and HFBR effluent during the two loads

Parameters	Units	Influent (1ry treated SWW)	1st load	%R.	2nd load	%R.
pH	mg/l		7.6		8.4	
Chemical Oxygen Demand (COD)	mg/l	4411.3±1634.5	346±214	85	970±529	76
Chemical Oxygen Demand soluble (COD)	mg/l	2039.2±1378	219.7±144		704±546	
Biological Oxygen Demand (BOD)	mg /l	1885.7±836.3	152±114	86	507±270	71
Total Suspended Solids (TSS)	mg/l	100.6±798	41.5±31	91	45±23	92
Phosphorous	mg/l	9.4±7.5	2.2±1.6		1.8±0.4	
Ammonia	mg/l	224.5±141.1	77±56	56	151±80	27
Total Kjeldahl Nitrogen	mg/l	362±218	117±63	56	197±100	41
Organic Nitrogen	mg/l	146.5±189	28±27		38±19	
Oil &Grease	mg/l	139±110.3	18.6±14	75	33±22	74

*Average of 60 samples

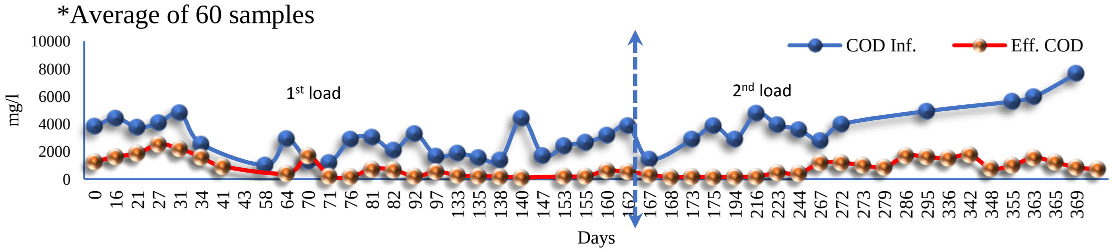


Fig. 2 COD concentration profile during the two loads

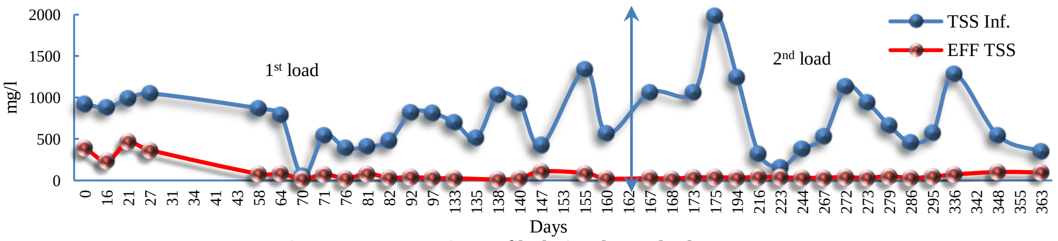


Fig. 3 TSS concentration profile during the two loads

The spaces for biomass growth were 25mm high in each sheet which prevented clogging, thus, no back wash was needed. During the steady state operation, the pH increased from 7.5 to 8.1 in the first 8 sheets where the highest carbon removal percentage was recorded. Metcalf & Eddy [29], stated that for carbonaceous removal, the optimal performance occurs near neutral PH. The data recorded in Table (3) showed that the higher removals values of COD and TSS took place in the top 8 sheets of average removal values 59 & 47%, respectively (Figure 4), with average residual values of 1654 and 148 mg/l, respectively. These results are also confirmed by Rodgers et al. 2008, who observed that most of COD concentration removed in the top 8 sheets of the HFBR for treating dairy wastewater. The removal efficiency after 24 sheets dropped to 11 and 20 % with average residual values of 987 and 106 mg/l of COD and TSS, respectively. At sheet 32 the removal efficiency of COD and TSS is slightly increased to 31 and 26% (Figure 4), with average residual values of 674 and 82 mg/l, respectively.

Table (3) Average* characterization of treated effluent from selected sheets of HFBR

sheet no.	pH	COD	CODs	TSS	NH_3	TKN	T.P	NO_2	NO_3
Raw	8.22	4048	2289	347	452	565.6	15.6	0.66	0.94
8	8.32	1654	1213	184	380.8	420	15.26	0.74	1.02
16	8.4	1108	874	124	319.2	364	15.2	0.5	0.92
24	8.41	987	703	106	291.2	336	11.32	0.94	1.2
32	8.38	674	512	82	218.4	252	9.84	0.62	0.88
40	8.4	500	378	40	168	180	6.42	0.83	0.68

*Average of 10 samples

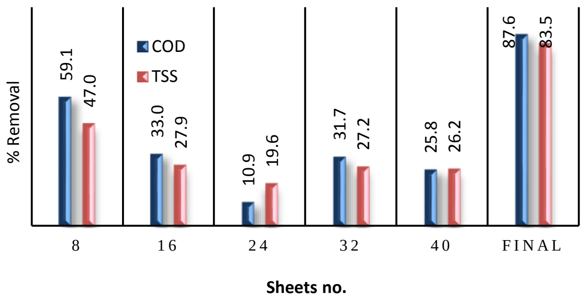


Fig. 4 Average COD &TSS removal profile on selected sheets

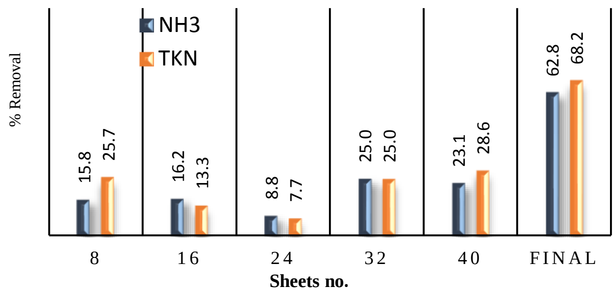


Fig. 5 Nitrogen removal profile on selected sheets

The results obtained indicated that average residual ammonia concentration in the final effluent reached 168 mg/l. Removal values was16% in the first 8 sheets and decreased to 8% after 24th sheet. But it increased to 25% and 23% after sheet 32 and 40 sheet of HFBR. Total Kjeldahl Nitrogen removal reached maximum value 28% on the average after 40th sheets (Figure 5). Also, the results showed that nitrification process is limited, it started after 16th sheet as the nitrate concentration value raised to 1.02mg/l (Table 3), but it continues with the almost the same or less concentration during the rest of the HFBR.

4. Conclusion

From the research work carried out in this study, it can be concluding the following:

1. Primary treatment of SWW is an essential treatment step before using any kind of treatment technology, as screening followed by sedimentation achieved 34% and 75% removal values of COD and TSS respectively.
2. The biodegradability test showed that the biodegradability rate constant (K) is 0.374/day and the ultimate BOD is 534 mg/l. Thus, biological treatment of SWW proved to be attenable for SWW.
3. HFBR system used for the treatment of SWW, it proves that the system could be one of the potential solutions to SWW treatment. The advantages of HFBR are the simplicity of operation, high performance and low cost of operation and maintenance, also, no clogging occurred during operation. The use of HFBR reduces the footprint of the treatment system compared with any other treatment technologies.
4. Two different OLR of 0.53 and 1.3 Kg COD/ m^2/ d. were studied for almost one year. The first OLR was the optimum load applied to the system giving the higher efficiency. The removal percentages during the first load of COD, BOD and TSS were 85%, 86% and 91%, respectively with residual concentration values of 346, 219 and 41 mg/l, respectively. The final effluent indicated that the technologies used were adequate to meet the discharge standards for irrigation of wooden trees and the discharge in sewerage system.

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